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LARCH MISTLETOE: SOME ECONOMIC CONSIDERATIONS OF ITS INJURIOUS EFFECTS.[1]

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INTRODUCTION.

During the past four years, in connection with other pathological problems in the forest, the writer has made an extensive survey of the damage to forest growth by some of the mistletoes of coniferous trees. These parasites are very widely distributed in the forest regions of the Northwest, and occur in such abundance in many localities as to assume a very serious aspect in relation to many forest problems. The extent and nature of the injury done vary greatly with the forest type, the topography, and, in some respects, with the climate. This is well shown in the regions in which investigations are now being conducted. In the dense part of many forest regions, as in the vicinity of the great lakes of Idaho, mistletoe does but little damage. However, in the more open stands bordering on the lakes or along the edge of the valleys of the Priest and Pend Oreille Rivers mistletoe occurs so abundantly on the various conifers as to interfere seriously with the development of some of the more valuable timber trees. About the shores of Lake Coeur d'Alene,

[1] The writer wishes to express his thanks to Mr. J. F. Pernot, without whose assistance the analysis of the trees would have been difficult, and to Mr. E. E. Hubert for assistance in the tabulations.

along the Spokane River Valley, and extending to the south into the Blue Mountains of Washington and Oregon the mistletoes are very abundant, especially on lodgepole pine (*Pinus contorta*), yellow pine (*Pinus ponderosa*), western larch (*Larix occidentalis*), and Douglas fir (*Pseudotsuga taxifolia*). In many localities the trees rapidly yield to the suppressing effects of these parasites, causing an open, ragged growth of the crowns, with the production of many brooms. The prevalence of a particular species of mistletoe varies greatly in the same general region. To illustrate: Along the hills fronting on the Pend Oreille River, Idaho, the lodgepole and yellow pine stands are heavily infected. Passing up the Priest River Valley, another mistletoe species appears, working considerable injury to the larch, whereas the same tree, wherever it occurs along the Pend Oreille River, is seldom infected. The yellow pine farther up in the Priest River Valley is not seriously attacked. In the Granite Creek drainage area and beyond the mountains to Sullivan Lake, in the Metaline Falls region of Washington, the larch is again very seriously infected, whereas this mistletoe seldom occurs on the divide between these points. The western hemlock (*Tsuga heterophylla*) in the forests of northern Idaho is practically free from mistletoe, as far as the observations have been carried. In a few of the more open valleys several collections of mistletoe have been made from this tree. At many points in Washington and British Columbia where the writer has had an opportunity to collect, the mistletoe on the hemlock seems more abundant. Numerous collections of mistletoes are at hand from many of the forests of southern Montana, and likewise from the northern part of that State and from central Idaho. A trip through Oregon, Washington, and British Columbia during 1913 yielded much information on the occurrence of mistletoes in those localities, so that it will soon be possible, with the additional data now (1915) being collected, to give a fairly detailed statement of the range of these parasites in the principal forest regions of the Northwest.

In order to obtain reliable figures on the damage to forest growth by these plants, special studies of a directly practical nature are now being conducted in several of the most important forests of the regions indicated. It is believed that the results from these studies will be applicable to all the forest areas of the Northwest where trees of the same species are found infected by the same mistletoe. At the same time, work of an experimental nature, both in the field and in the laboratory, is adding to our knowledge of these parasites. This work is being continued, as having a practical bearing on the mistletoe problem, and will be reported upon as time and occasion permit.

THE LARCH MISTLETOE.

This bulletin deals in the main with the immediate practical results of an investigation of the injurious effects of the larch mistletoe on its host in the Blue Mountain region of Oregon and serves to introduce one of a series of studies on the mistletoes of coniferous trees in general. The larch mistletoe (fig. 1), originally named *Razoumofskya douglasii laricis* by Piper[1] and given as a subspecies of the Douglas-fir mistletoe, has recently been raised by the same writer[2] to the rank of a full species under the following name and description:

Razoumofskya laricis Piper. Pistillate plants olivaceous, clustered, 5–8 cm. long, branched; joints 1.5–2 mm. thick, sharply 4 angled; staminate swollen, yellow, the flowers in short spikes; lobes ovate, acute; fruit oblong, acutish, bluish, 4 mm. long. Common on *Larix occidentalis*.

The investigation was begun in the Whitman National Forest, Oreg. For some time the general and gradual deterioration of the western larch had been reported as occurring throughout the entire Blue Mountain region. The writer was not aware of the great prevalence of the larch mistletoe in this region until his visit there during the early spring of 1913. From a preliminary survey it soon developed that the primary cause of the deterioration of the larch resulted from the suppressing effects of mistletoe. A probable secondary factor on some of the more exposed sites seemed to be certain climatic influences unfavorable to the host but promoting the better development and spread of the parasite.

FIG. 1.—Staminate plants of *Razoumofskya laricis*. Note the hypertrophy of the branch.

THE FOREST.

The Blue Mountains, in which further studies of the mistletoes are in progress, are well covered with forests. The yellow pine pre-

[1] Piper, C. V. Flora of the State of Washington. U. S. Nat. Mus., Contrib. Nat. Herbarium, v. 11, p. 222. 1906.

[2] Piper, C. V., and Beattie, R. K. Flora of Southeastern Washington and Adjacent Idaho, p. 80. Lancaster, Pa., 1914.

dominates as the principal tree on all the drier slopes and bench lands. This gives an open character to the forest and is of some significance as regards the growth of mistletoe on the larch wherever this tree is associated with the yellow pine. On the lower elevations the yellow pine often occurs in pure parklike stands, with a ground cover quite characteristic of the typical yellow-pine formation, usually indicated by the absence of any great amount of forest litter and by the uniformity and the small number of species of herbaceous and shrublike plants. On the south slopes and low, dry ridges, where the stand is very open, the yellow pine is quite generally infected with its particular mistletoe, working great injury to the tree. At higher elevations in more moist situations, or even at the same level on protected parts of the typical stand, the yellow pine becomes mixed with larch, Douglas fir, white fir, and lodgepole pine. The yellow pine gives way to greater percentages of larch, Douglas fir, and lodgepole pine on the north and east slopes. The two last-named species support large quantities of their respective mistletoes wherever the conditions are favorable for the development of these parasites. The larch predominates in many north-slope stands, especially in the more open situations. Other forest types in which the larch occurs above 6,500 feet or more are of little importance in this connection, since the species of the types at this elevation are not as seriously infected by mistletoe as those on north slopes of 5,000 feet altitude and less.

The influence of drainage, slope, and the general moisture conditions of the soil on the distribution and vigor of the western larch is well shown in the region studied and is likewise reflected in the prevalence and distribution of its principal parasite. Owing to the general prevailing dryness of the region, the maximum development of the larch is attained in moist draws or in fertile valleys not parallel with the direction of the prevailing winds. In such situations the tree is usually quite free from mistletoe, and uninfected trees often attain a diameter, breast high, of 60 inches or more. A full crown composed of the original branches is retained until late in life, the tree showing few defects except an occasional root-rot or a dead top occasioned by agents other than mistletoe. These situations are more favorable to the development of the host than to the mistletoe occasionally found upon it and must be considered the best sites for growing larch in these regions. On the drier slopes and benches, where the larch is associated more with yellow pine, the influence of the site on the vigor of the mistletoe is at once expressed by its greater abundance and its effects on its host, causing smaller diameters and thinner crowns on the infected trees. Occasionally trees in exactly similar situations for some reason escape the ravages of the mistletoe and attain a size of considerable proportions. The full

crown and degree of vigor shown by these trees late in life prove conclusively that the ragged, suppressed condition of their neighbors is not due wholly to unfavorable climatic or soil conditions, but to the effect of the mistletoe upon them.

On some north slopes where the larch is crowded by lodgepole pine and white fir it becomes suppressed for a time very early in life, as indicated by the zone of suppression in the older trees. Those trees finally escaping by their more rapid growth from the influence of their neighbors usually become infected by mistletoe when the crown spreads out to the light and air above. The opportunities for the mistletoe to attack suppressed trees with crowns overtopped by other species not subject to its ravages are not as great as when the trees are standing more in the open. This is due in part to the other species protecting the larch from seed falling on it, and in part to the fact that permanent tissue incapable of being penetrated by the primary sinker is more rapidly developed in the case of suppressed individuals. New growth is of short duration and fewer vulnerable points of easy infection exist. If the infection of the suppressed trees does occur and the infection succeeds for a time, the mistletoe plant may itself become suppressed, partly from a poor nutrient relationship with its host and partly through lack of light, and eventually may die without producing new infections higher up. The signs of old infections are frequently noted in the area of the zone of suppression in trees that have afterwards escaped from the crowding of their neighbors. If such trees again become infected later in life, they may attain a fair merchantable size before the influence of the parasite is made manifest.

PHYSICAL AND CLIMATIC FEATURES OF THE FOREST REGION.

The later geological history of the Blue Mountains, in which the Whitman National Forest is located, is one of a great basaltic uplift surrounding but not submerging the older granitic formations. The several high and low laterally arranged ridges are composed in the main of granitic rocks, forming a type of soil upon which the yellow pine usually becomes the climax species. Other soil characters induced by local variations of climate, slope, and type of ground cover influence the distribution of the forest trees of this region to a marked degree, and indirectly that of the mistletoe.

Summarizing the chief climatic characteristics of the region, compiled from the reports of the United States Weather Bureau, they are (1) scanty rainfall, (2) wide range of temperatures, (3) low absolute humidity, (4) rapid evaporation, and (5) an abundance of sunshine. The influence of such climatic conditions may be considered in general as unfavorable in a few localities to the best

development of the larch, but decidedly favorable to the mistletoe found upon it. This is at once evident to those familiar with the environmental requirements of host and parasite. The region affords a most instructive study of the advance and predominance of a forest-tree parasite on its host, showing this advance to be in as near an exact proportion as the conditions for its optimum development become more favorable.

The problem of the mistletoes in their ecological relationships, regardless of the fact that they are parasitic, is similar to that of all chlorophyllaceous plants; hence, they respond to light, gravity, and

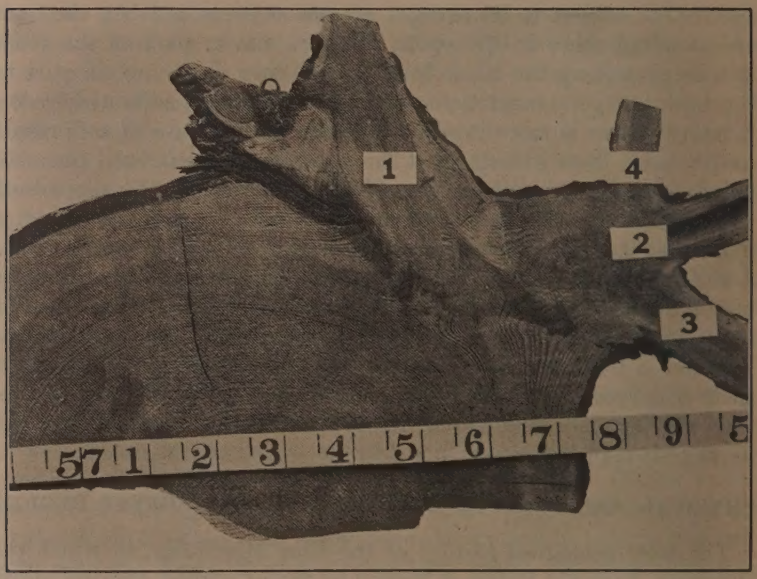

FIG. 2.—Cross section of a part of a trunk of a larch tree, showing the regeneration of branches from the same whorl to the fourth generation. (Tape in feet graduated in tenths.)

chemical influences, and in a far less degree to the influences of temperature and moisture. How, then, do the ecological requirements of the larch mistletoe hold with the climate of the region described, over which the parasite is widely distributed? The great variation in temperature, occasionally abnormally high, and the late, early, and winterkilling frosts of some sections, although seriously injuring the host, produce but little effect on the parasite. The uniform dryness of the air at all seasons of the year throughout the region does not greatly influence the mistletoe plant, which is essentially xerophytic. On the other hand, the large percentage of sunshiny days and the absence of clinging fogs are directly favorable to the parasite, as it is

positively phototropic. The possible influence of the low absolute humidity and rapid evaporation on the entrance of host, reproduction, etc., is counteracted by the parasite by means of special structures enabling it to withstand long periods of drought.

Probably no factor of the region so greatly aids the destructive effects of the mistletoe on the larch as the high, strong winds so prevalent in these mountains. The velocity of the winds is sometimes very great. During 1913 hundreds of reserved yellow pines on the sales area of the Whitman National Forest were uprooted. The wind in this case was materially aided by the insecure rooting of the trees on the surface of a hard stratum of rocks and gravel, together with a certain amount of decay in the brace roots. This is a condition often found in cases of this kind.

FIG. 3.—A larch tree of greatly reduced vigor caused by the formation of great witches'-brooms and the accumulation of dead leaves and lichens in them. Note that the tips of the branches, also the witches'-brooms in the upper portion of the crown, are dying.

Strong winds probably do greater injury to the larch than to any other conifer. An examination of the branching or crown of a mature or middle-aged healthy larch will show that in most cases, especially in windy regions, the tree has been able to reach the standard size only through the production of several generations of branches replacing those broken off by the wind and by other causes (fig. 2). The loss of branches through crowding or natural pruning is not here considered. Trees standing under open conditions from the beginning will show this interesting phenomenon of regeneration. Increasing age, within a certain limit, on the part of the main trunk does not interfere with the anatomical and physiological connections of old branches. Consequently, branches forming at any age sufficiently high on the trunk to escape the influence of suppression should and would remain intact, barring all deteriorating influences, during the natural life of the tree.

Trees with wood exhibiting a natural brittleness, which is always very pronounced at the bases of branches, suffer greatly from breakage by the wind. The western larch is especially subject to this form of injury. The brittleness of its branches at their point of attachment with the main trunk is so pronounced that it is not un-

common to find them lopped off by the wind. This is especially true of tall stems that have come up in close canopy and afterwards become more or less isolated. In the case of the larch the ill effects of the wind are greatly augmented by the heavy loads of long, trailing lichens (*Alectoria fremontii* Tuck. and *Usnea longissima* Ach.) supported by the branches (fig. 3). During rainy periods these lichens, through the absorption of large quantities of water, increase the weight of the branch by several pounds and, hanging downward in a saturated condition, offer a greater resistance to the wind. The amount of damage to the larch in many locations from this cause alone is much greater than is ordinarily supposed. In the study in the Whitman National Forest it developed that the injury to the larch by mistletoe (aside from the gradual effects of suppression by brooming up the branches and reducing the assimilatory surface) was in a large measure due to the pruning by the wind of the many branches which, being heavily loaded with witches'-brooms, caused an increased weight to be exerted at their bases. These brooms are often formed far out on the branch and become densely matted with dead leaves and lichens (fig. 3). This increase in weight often amounts to several pounds more than that of a normal branch of the same age and size (Table II) and is further increased by the absorption of water during rainy weather. In the winter the broom furnishes a collecting place for snow. It is very evident how the resultant of the two forces, viz, the wind in a lateral and the weight of the broom-laden branch in a vertical direction, may bring about the removal of all the main original branches (fig. 4). It is not uncommon to find large heaps of branches heavily loaded with brooms under the infected tree. Up to this point the breakage of normal wood uninfected by mistletoe roots has alone been considered.

FIG. 4.—A larch, showing the original crown entirely removed by brooming. The secondary crown is also broomed. The witches'-brooms support large quantities of "black moss" (*Alectoria fremontii* Tuck.), which grows over and mats the foliar spurs.

The infected wood of the branch, either at its base or other portions, where not too greatly enlarged by the stimulating effects of the parasite, requires a much smaller force to break it at the point of infection than is the case in normal branches of like age and thickness. The penetration and embedding of the vertical root system of the parasite in the wood of the host add nothing to the strength of the infected tissue, but diminish its normal strength when the force, as in the case of the wind, is applied at right angles to the grain of the infected branch. Since numerous infections occur at the bases of branches, the point of greatest stress, much injury to the tree results. The meristematic tissue in the cambium layer at the point

FIG. 5.—Cross section of the trunk of a larch tree, showing a typical basal branch burl. Note that the dead wood is attacked by borers which do not encroach upon the living sapwood.

where the branch breaks usually produces secondary branches (see fig. 2). These in turn may become infected and are lopped off, so that eventually great burls are produced at this point on the trunk (fig. 5), seriously reducing the merchantable material. The dead wood thus exposed is a place of entrance for insects and fungi. Since it requires years for the secondary branches to attain a size and assimilatory surface capable of supporting the present bulk of the trunk, the vigor of the tree is gradually reduced. The younger portion of the crown above, being continually encroached upon by the parasite, is not able to supply the deficiency in food materials, and the tree, merely existing for a time, finally becomes a prey to various

deteriorating agents and eventually dies before reaching its maximum development (fig. 6). The radial dimensions of the last annual ring of trees in the final stages of mistletoe suppression (fig. 7)

FIG. 6.—A larch tree in the last stages of mistletoe suppression. A few of the witches'-brooms contain living branches. The tree was making no perceptible increment and was far below the normal size for the region. It was necessary to clear away from the base of the tree the heap of fallen witches'-brooms before it could be cut.

FIG. 7.—Two larch trees barely living, as evidenced by dissection of the bole. Note the very large witches'-brooms and numerous dead branches.

were often so fine and narrow that they could be counted only with the aid of a compound microscope. In some of the worst cases the tree was able to produce but a single layer of tracheids in a year.

In so far as climate influences the prevalence and destructive effects of the larch mistletoe, that of the Blue Mountain region is most favorable. It might be here added that when a particular tree species has succeeded in establishing itself outside of what may be considered its optimum range and at the same time is followed up by a most destructive parasite which responds favorably to the habitat, the rapid deterioration of the species must necessarily follow, at least in the more unfavorable sites.

FUNGOUS ENEMIES OF THE LARCH.

The larch on the tract examined was not attacked to any extent by fungi. The fungi collected were not present in sufficient quantity nor were their effects sufficiently evident to be considered the prime factor in the universal deterioration of the tree. The dead wood and bark of the mistletoe burls were usually infested by the larvæ of *Melanophila drummondi* Kirby (figs. 5 and 8) and occasionally were followed by a fungus causing a black stain. Two burls were found infected

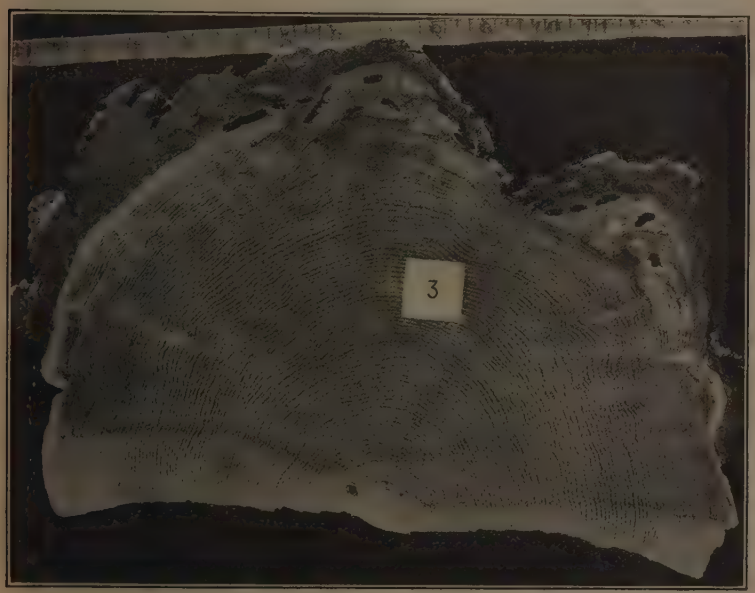

FIG. 8.—Cross section of the trunk of a larch tree, showing characteristic fan-shaped burl tissues resulting from an original infection when the tree was 7 years old. The tree was 145 years old when cut. Note the presence of borers. (Tape in feet graduated in twelfths.)

with *Trametes pini* (Brot.) Fr. (figs. 5 and 9), but here, as in a number of other cases where fungi had entered at the burl, the hardness and pitchy condition of the wood counteracted the advance of the fungus, and it had not spread much beyond the burl tissue. It is safe to state, from long field observations in other regions, that mistletoe burls furnish admirable starting points for fungi; but since the burl in its early stages is very pitchy (fig. 10) and the dead wood becomes pronounced only after the tree is greatly injured by the mistletoe itself, the effect of the fungi is to destroy later the merchantability of the tree, and the mistletoe may not be the original cause of its deterioration.

THE EFFECTS OF MISTLETOE ON ITS HOST.

A preliminary survey by the strip method made at the foot of a north slope and partly on the level resulted in the accumulation of the data given in Table I, showing conclusively that the larch in this region is heavily infected with mistletoe. No attempt was made to ascertain the age of the trees given here, so as to show the degree of suppression. A good idea may be obtained, however, of the nature of the infection, distribution, and quantity of mistletoe present on the trees. In general, the height of the trees here recorded is somewhat less than that of normal or uninfected trees in the same region.

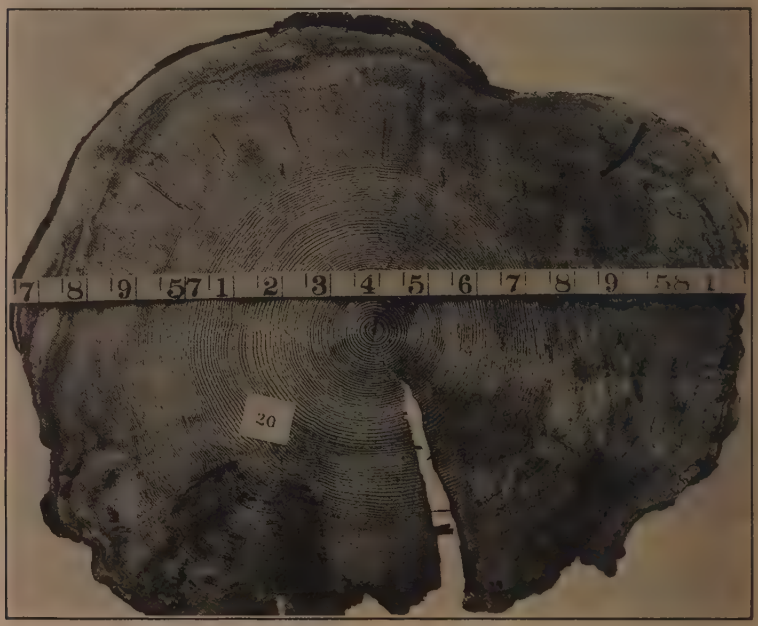

FIG. 9.—Cross section of the trunk of a larch tree, showing a large burl with white cellulose pits caused by *Trametes pini*. Note the small amount of living wood and that the dry wood is attacked by fungi and insects. (Tape in feet graduated in tenths.)

The youngest specimen found infected was less than 5 years old, which means, of course, that such early infection will not allow a very high state of merchantability to be attained, even if the young tree is not killed prematurely. Usually very young growth first becomes infected somewhere on the trunk where the bark is not yet protected by cork (fig. 11). The infection of very young seedlings causes them to assume various abnormal shapes and positions, especially when the mistletoe is confined to one side of the stem. Burl

tissues begin to form usually within a comparatively short time, from one to two years in young plants. If the infection occurs on the stem near the base of a branch, the cortical root system advances into the bast tissues of the branch, initiating a burl or witches'-broom at that point (fig. 1). The extension of the cortical roots upward along the main trunk is sometimes sufficiently rapid to keep within the 4 to 5 year old portion of the stem, although the larch mistletoe seldom

FIG. 10.—Cross section of a trunk of a larch tree with a large burl, showing its structure and a large pitch pocket.

spreads very far from the point of original infection. The parasite, however, usually travels more rapidly along the young shoots which develop in number at the place of first infection. The spread of the parasite outwardly along the branch or upwardly along the leader may be hastened by the dissemination of seeds from the older infections. In this manner the last year's growth is often infected, and even the terminal bud. The branches of the parasite eventually fall away, leaving scars easily discernible on the older parts of the young trees (fig. 1).

TABLE I.—*Extent and nature of mistletoe infection in 36 larch trees in the Whitman National Forest.*

Tree No.	Breast-high diameter.	Height of tree.	Number of burls.		Number of witches'-brooms.				General vigor of tree.	General merchantable condition.
			On trunk.	At base of branches.	At base of branches.	On branches.	Total on tree.	Fallen from tree.		
	Inches.	*Feet.*								
12	7	51	1	4	5	13	18	1	Poor..	.....
16	7	68	1	4	6	10	16	1	...do...	Poor.
15	9	75	0	0	0	0	0	0	Good..	Good.
29	10	50	0	0	0	18	18	1	Fair...	Do.
11	11	83	0	2	2	12	14	1	...do...	Do.
9	12	64	0	0	4	15	19	2	...do...	Do.
10	12	66	0	0	3	16	19	0	...do...	Do.
14	13	95	0	0	6	12	18	2	...do...	Fair.
7	14	78	0	0	0	0	0	0	Good..	Good.
20	14	122	0	0	0	0	0	0	...do...	Do.
5	15	98	1	0	4	8	12	2	Fair..	Fair.
13	15	84	0	3	4	15	19	3	...do...	Do.
17	15	83	0	0	0	0	0	0	Good..	Good.
18	16	88	1	2	4	20	24	3	Poor..	Poor.
1	17	85	0	4	5	15	20	17	...do...	Do.
21	17	88	2	8	4	20	24	3	...do...	Do.
22	17	90	0	1	2	11	13	1	...do...	Good.
19	18	99	1	0	3	8	11	1	Fair...	Do.
25	18	103	0	0	0	0	0	0	Good..	Do.
33	18	80	1	1	3	5	8	3	Fair...	Do.
2	19	99	0	0	0	0	0	0	Good..	Do.
23	20	103	1	2	4	18	21	4	Fair...	Fair.
24	20	120	0	3	3	20	23	6	...do...	Do.
26	20	109	3	4	3	21	23	4	...do...	Do.
8	22	107	1	1	3	10	13	0	...do...	Good.
3	23	100	2	4	8	8	16	9	Poor..	Fair.
6	23	110	3	6	5	16	21	7	...do...	Poor.
32	23	109	4	2	1	10	11	1	...do...	Do.
30	24	110	1	2	3	15	18	4	Fair...	Fair.
36	25	111	2	3	4	10	14	4	Poor..	Poor.
27	28	126	0	0	0	0	0	0	Good..	Good.
28	28	110	1	2	1	10	11	2	Fair...	Do.
31	28	119	3	1	2	20	22	2	Poor..	Poor.
35	29	123	3	4	6	10	16	2	...do...	Do.
4	29	125	0	14	5	20	25	6	...do...	Do.
34	30	120	0	3	2	6	8	0	Fair...	Fair.

Owing to the slower growth of the branches in length as compared to the stem, the cortical roots of the mistletoe are enabled to extend into the older part of the 2-year-old internodes. After a time the branch is suppressed and the terminal bud becomes infected, resulting in a terminal broom. The cortical roots likewise penetrate the foliar spurs, causing them to become greatly enlarged, with the result that few leaves are produced (fig. 12). It is remarkable how rapidly in some instances the burl tissues become differentiated. A slight swelling is first noticeable; then the bark begins to lose its fresh appearance, becomes rough around the edges of the infected tissues, and finally separates altogether from the normal bark (fig. 11). The vertical roots of the parasite continue to live for many years, elongating with the same rapidity with which the annual increment of the host is laid down. The hypertrophied tissues resulting from these early infections on the stem spread out in fanlike shapes when viewed in cross section (figs. 8 and 10). Original infections on branches not only cause a local hypertrophy of the immediately

infected area (fig. 13), but large brooms are almost invariably produced.

In mistletoe regions no trees of any age are safe from infection. A great many trees surrounded by other species not attacked by the

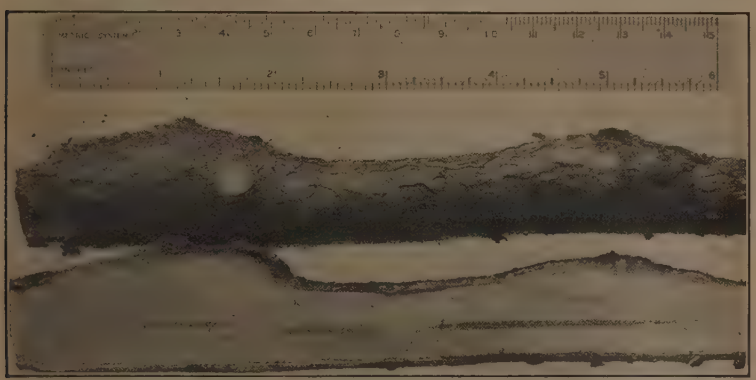

FIG. 11.—The main stem of a young larch, showing two separate infections, one at the whorl of branches and the other on the internode. Both infections are of the same age, as indicated by the large primary sinkers, which terminate at the same annual ring. Note the rough bark on the swellings, the beginning of typical trunk burls. The branches of the mistletoe have fallen, but the sinkers are still living and will remain alive for an indefinite period, stimulating the host tissues to a greater development. The central areas of the burl soon die, leaving an open wound.

same mistletoe escape early infection and grow to a fair size, with normal, healthy crowns. Such uninfected trees are always conspicuous among their more heavily infected neighbors. These trees are eventually attacked, but owing to the advantage of a somewhat isolated position, they may not become badly infected, since the seeds must be brought from a distance greater than the natural expelling force of the seed capsule is capable of exerting. Undoubtedly this force is aided by the wind. The final result is the infection of the terminal twigs, and in most cases those of the lower branches. The infection gradually spreads upward; the branches either become broomed

FIG. 12.—A larch twig, showing the abnormal size of the foliar spurs when stimulated by the parasite. These spurs are nearly four times the size of the normal spurs on the same branch.

and are broken off, followed in many cases by a secondary crown (figs. 3, 4, 6, and 7), too late to supply the deficiency in food materials; or the vigor of the present bulk growth and the vitality of the tree are reduced by a general infection throughout the entire crown. The latter type of mistletoe injury frequently occurs. The tree seems to become infected at many different parts of the crown at once, and while the branches are not broken by the formation of large brooms, the vitality of the host gradually sinks under the drain on its resources of so widespread an infection. When young trees are infected there is such an excessive broom development by the time they have reached pole size that the original crown has practically

FIG. 13.—A common type of original infection on a larch branch, showing the beginning of branch witches'-brooms.

disappeared. Bushy secondary branches grow out from the stumps of the old ones, and the lopping process may be continued to a third or fourth generation of branches (fig. 2). The width of the secondary crowns becomes less and less, until practically nothing remains but the stubs of the former branches, bearing a few straggling green twigs (figs. 3, 6, and 7). By this means the assimilatory surface of the tree is gradually reduced. During the period between the fall of the primary and the appearance of the secondary branches, the tree is robbed of a great amount of food material necessary to maintain its vigor at its present stage, and it begins to show signs of

developing a "spike top" (figs. 4, 6, and 7). All heavily infected trees by the time they have reached the age of 200 years, if they succeed in living to that age, have developed a "spike top" (Table II).

Occasionally infected trees attain a considerable size, due to the fact that the original infections occurred chiefly at the bases of the branches and did not spread. The attendant broom formation occurring on the branches next to the trunk allows the retention of the branches for a longer time than if brooms were developed farther out on the branch. The merchantability of the tree is greatly reduced, however, by the formation of a series of basal branch burls, causing streaks of pitchy wood to extend along the trunk from one burl to another.

The spread of the parasite in the direction of the prevailing winds was very interestingly shown in a number of cases. One case in particular was noted in which a series of trees of nearly the same age standing in a row extending in the general direction of the more constant winds indicated that the infection had gradually traveled from the first and most seriously infected specimen to those least infected at the other end of the row. These trees had apparently originated under the protection of an old windfall. Since there were no infected trees immediately to the right or left, it is fairly evident that the wind was a factor in seed distribution and also determined the direction of distribution. In order to appreciate thoroughly the significance of the effects of mistletoe on the larch, a study should be made of figures 3, 4, 6, and 7, representing different stages of suppression and various types of infection.

On the drier slopes, from 80 to 90 per cent of the larch of all ages has been found infected. On the more favorable sites, the percentage of infection was very low and therefore did not interfere seriously with the best development of the species. (See trees Nos. 40 and 41, Table II.)

After the preliminary survey, and in order to answer definitely the question whether or not mistletoe is as great an enemy to the host as outward appearance seems to indicate and to obtain, as near as possible, comparable figures on mistletoe injury, 45 infected and uninfected trees were cut and such measurements taken as were thought necessary for the needs of the problem in hand. These data, along with many other observations having a bearing on the subject, have been arranged in Table II, whereby it is possible to follow out the main factors operative in the deterioration or suppression of the trees studied and by means of which fairly conclusive comparisons may be drawn.

TABLE II.—*Comparison of 45 larch trees in the Whitman National Forest with respect to mistletoe infection.*

[Abbreviations: In columns 14 and 40, increasing degree of infection is shown by the number of cross marks; in columns 26, 31, and 32, B=borers, F=fungi, S=sound, St=stain; in column 36, D=dominant, I=intermediate, S=suppressed.]

Age of tree.	Tree No.	Branch burls.		Branches on burls.		Highest point of infection.	Branch witches'-brooms.	Length of spike top.	Average weight of—		Average diameter of branch.	
		Number.	Average height.	Living.	Originally.				Normal branches.	Branch witches'-brooms.	Supporting witches'-brooms.	Normal, same part of whorl.
1	2	3	4	5	6	7	8	9	10	11	12	13
Yrs.			*Feet.*			*Feet.*		*Feet.*	*Pounds.*	*Pounds.*	*Inches.*	*Inches.*
30	45											
63	27											
63	42					47.0	7		2.0	3.0	0.5	0.8
74	25											
90	6					Tip.						
94	1											
96	9											
96	43	2	20.0	8	10	57.0	6		3.0	4.5	1.0	1.5
100	7	3	35.3	10	18	80.0	6			4.5	1.3	
105	8	1	23.0	3	4	77.0	5		5.25	3.2	1.3	1.5
106	10	1	23.0	2	2	59.0	24		1.6	3.2	1.0	.75
107	11											
111	4											
119	14											
122	25	8	22.4	23	38	55.5	9			3.8	1.0	
123	5	2	38.0	10	14	82.0	18		2.0	3.0	1.0	.75
123	41											
128	13	3	25.3	15	7	88.5	38		3.2	6.0	1.75	1.50
136	12					108.0	17			8.0	1.0	
143	22											
145	3	5	56.4	15	21	92.0	13		4.5	8.0	1.0	1.75
145	30											
147	19											
180	23	12	41.9	37	72	101.0	10		6.0	8.5	1.0	2.10
183	31	6	49.1	6	20	109.0	6		6.0	10.0	1.0	2.0
205	15	12	35.9	14	40	Tip.	(*a*)			(*a*)		
216	16											
222	17	5	37.4	9	21	110.0	11		5.0	8.0	.95	1.8
224	36	5	39.2	10	31	Tip.	1	16				
225	29	4	47.0	3	25	Tip.	(*a*)		(*b*)		(*b*)	
226	35	12	49.0	5	58	Tip.	1		(*c*)			
227	33	9	71.2	23	51	Tip.	10	10				
229	28	11	45.5	17	53	Tip.	10	12	(*d*)		(*d*)	
233	34	5	53.0	3	28	Tip.	(*a*)		(*d*)		(*d*)	
235	18	6	48.3	7	33	Tip.			(*e*)	(*e*)		
245	30	5	54.4	4	19				(*f*)			
245	37	4	43.0	3	21	93.0	2		(*g*)			
248	32	7	42.0	7	29	Tip.	1			25.0		
249	2	12	37.5	19	85	Tip.		7	(*h*)			
249	12	10	49.3	5	46			24	(*i*)			
252	38	6	67.4	10	39	Tip.			(*j*)			
253	20	3	34.6	2	18	Tip.		42	(*k*)			
271	24											
566	40											
623	41											

a Branch witches'-brooms fallen to ground.
b Most original branches broken off.
c One original branch.
d Original branches broken off.
e Crown secondary.
f Branches fallen; last stage.
g Crown secondary, infected.
h Branches all fallen.
i Upper crown heavily infected.
j Branches secondary.
k Branches mostly fallen.

TABLE II.—*Comparison of 45 larch trees in the Whitman National Forest with respect to mistletoe infection*—Continued.

Age of tree.	Tree No.	Degree of infection.	Burls on trunk.												Rings in sapwood (average).	
			Number.	Average height from ground.	Occupied by each burl (per cent).									Condition.	Width.	Number.
					Transverse section through center.			Circumference.			Transverse area of living trees.					
					1st	2d	3d	1st	2d	3d	1st	2d	3d			
1	2	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Yrs.				*Feet.*											*In.*	
30	45	xxx	1	4.5												
63	27	0													0.9	21.3
63	42	xx													.53	16.0
74	26	0													1.00	21.0
90	6	xxx	2	13.5	65	95		65	65		33	100		S	.46	25.0
94	1	0													1.34	13.0
96	9	0													1.35	27.2
96	43	xxx	1	15.0	50			100			10				1.12	23.2
100	7	xxx	3	17.0	55	6	15	100	28	20	100	100	100	S	1.29	25.6
105	8	xx	1	11.0	20			28			100			S	1.30	24.0
106	10	xxx	1	6.0	95			95			100			S	.84	31.2
107	11	0													1.32	18.5
111	4	xx													1.25	28.2
119	14	0													1.62	21.3
122	25	xxx	1	Base.	60			35			95			B	1.14	30.6
123	5	xx	1	38.0	100			100			70			St	.77	32.6
123	41	0													1.50	30.0
128	13	xx													.81	25.0
136	21	xx													.87	35.0
143	22	0													.88	24.1
145	3	xxx	3	11.2	60	35	20	60	40	15	40	50	100	B, F	.78	34.7
145	39	0													1.34	23.7
147	19	0													1.43	28.6
180	23	xxx													.71	15.2
183	31	xxx	1	16.5	50			50			20			F	.91	38.7
205	15	xxxx	1	23.0	40			42			40			B, F	.52	50.4
216	16	x	1	10.0	70			85			60			B	1.02	34.6
222	17	xxx	2	19.5	40	50		50	45		25	90		B	1.00	36.7
224	36	xxxx													.38	29.2
225	29	xxxx	1	48.0	60			40			10				.46	41.7
226	35	xxxx	1		35			40			95			S	.79	43.9
227	33	xx													.51	45.3
229	28	xxxx	1	27.0	40			50			20			B, St	.43	47.4
233	34	xxxx													.53	35.8
235	18	xx													.56	44.1
245	30	xxxx													.43	42.4
245	37	xxx	1	46.0	100			100			40			B, F	1.11	37.1
248	32	xxx													.54	43.2
249	2	xxx													.38	33.0
249	12	xxxx	1												.56	50.4
252	38	xxx													.67	41.7
253	20	xxxx	1	49.0	80			80			25			B, F	.68	57.0
271	24	0													.88	44.0
566	40	0														
623	41	0														

TABLE II.—*Comparison of 45 larch trees in the Whitman National Forest with respect to mistletoe infection*—Continued.

Age of tree.	Tree No.	Rings comprising present period of suppression.			Condition of heartwood.	Height (feet).		Full volume, b. m.	Dominance.	Diameter, breast high.	Height of stump.	Growth for last 10 years at stump.	Degree of infection.
		Width.	Number.	Condition.		Total.	Merchantable.						
1	2	29	30	31	32	33	34	35	36	37	38	39	40
Yrs.		*Inches.*						*Feet.*		*In.*	*Feet.*	*In.*	
30	45	0.25	15	S	S	7	.....	0	S	0.75	.....	.....	xxx
63	27	0	0	S	S	60	.....	40	I	6.65	1.0	0.60	0
63	42	.5	20	S	S	53	.....	25	D	5	1.0	2.80	[a] xx
74	26	0	0	S	S	52	.....	20	I	6	1.0	.70	0
90	6	.4	30	B	B	51	.....	20	S	6	1.0	.10	xxx
94	1	0	0	S	S	97	58	340	D	15	1.2	1.20	0
96	9	0	0	S	S	72	32	80	I	9	1.0	1.00	0
96	43	.4	30	S	S	65	30	20	D	6	1.0	.10	xxx
100	7	.2	6	S	S	93	48	165	D	11	1.3	.80	xxx
105	8	.3	4	S	S	95	64	265	D	14	1.2	1.00	xx
106	10	.4	30	S	S	67	0	40	I	7	1.0	.40	xxx
107	11	0	0	S	S	93	64	325	D	16	1.0	2.00	0
111	4	.4	14	S	S	85	48	140	I	11	1.3	.60	xx
119	14	0	0	S	S	122	80	665	D	14	1.5	2.00	0
122	25	0	0	S	S	64.5	16	75	D	9	1.5	.70	xxx
123	5	.3	20	S	S	84	48	170	D	11.5	1.3	.10	xx
123	44	0	0	S	S	95	50	0	D	20	.....	.....	0
128	13	.25	10	S	S	98.5	64	435	D	17	1.5	.50	xx
136	21	.2	10	S	S	114	66	485	D	19.5	1.5	.40	xx
143	22	0	0	S	S	113.5	82	595	D	18	1.5	.80	0
145	3	.2	30	S	S	95	64	240	D	13	1.5	.30	xxx
145	39	0	0	S	S	123	94	1,045	D	22	1.6	1.30	0
147	19	0	0	S	S	102	80	550	D	17	1.5	1.20	0
180	23	2.5	30	S	S	113	82	920	D	21.5	1.5	.10	xxx
183	31	.15	10	S	S	119	82	1,010	D	24	1.5	.30	xxx
205	15	1.2	86	S	S	100	64	430	D	17	1.5	.20	xxxx
216	16	1.2	10	S	S	131	92	720	D	18	1.0	.40	x
222	17	.25	25	S	S	119	80	885	D	21	1.5	.70	xxx
224	36	.15	20	S	S	86	50	160	I	11	1.5	.10	xxxx
225	29	.5	40	S	S	106	82	590	D	19	1.5	.20	xxxx
226	35	.45	35	S	S	121	82	790	D	20	1.5	.20	xxxx
227	33	.4	38	S	S	131	98	1,540	D	26	1.8	.10	xx
229	28	.25	36	S	S	107.5	82	700	D	18	1.0	.10	xxxx
233	34	.15	14	S	S	104.5	65	380	D	16	1.5	.....	xxxx
235	18	1.5	73	S	S	121	80	820	D	20	1.0	.20	xx
245	30	.75	48	S	S	113.5	82	675	D	19	1.3	.20	xxxx
245	37	1.15	6	S	S	97	60	380	I	14	1.5	.60	xxx
248	32	.25	20	S	S	84.5	50	305	S	14	1.5	.10	xxx
249	2	2.5	80	S	S	112	90	905	D	21	1.4	.20	xxx
249	12	1.9	95	S	S	88	48	470	D	18	1.0	.06	xxxx
252	38	.25	20	S	S	120.5	82	780	D	21	1.5	.20	xxx
253	20	.6	50	S	S	112	81	870	D	21	1.4	.20	xxxx
271	24	0	0	S	S	133.5	98	1,905	D	31	1.5	.40	0
566	40	.....	.....	.....	S	160	.....	.....	.....	43	2.0	.40	0
623	41	.....	.....	.....	S	165	.....	.....	.....	51	2.0	.50	0

[a] The section passed through burl tissues.

The trees were selected from a comparatively small area after the preliminary survey had shown the nature of the deterioration to be universal and similar over large areas of the same type of stand. Although the numerical basis for the figures in the table is very meager, interesting results are shown, which fully justify the arrangement. In the absence of suitable volume-table studies of the normal growth of the same age class for the region, the arrangement of the table is based entirely on the trees felled for study. An increasing degree of infection is indicated by the larger number of cross marks employed (columns 14 and 40). Selecting trees of the same age, the study of the table may proceed as follows: Trees Nos. 42 and 27 are of the same age. The infection of No. 42 is xx; of No. 27, 0. By consulting column 27 the average width of sapwood for tree No. 42 is found to be 0.53 inch, and column 28 shows that the sapwood consists of an average of 16 rings; tree No. 27 has an average width of sapwood of 0.9 inch, with an average of 21.3 rings. Tree No. 42 showed a present period of suppression of 20 rings (column 30), the combined width of which is 0.5 inch (column 29); tree No. 27 has no present suppression and is marked 0 in the table. The condition of the sapwood, sound for both trees (column 31), indicates the absence of secondary causes of deterioration, as does in like manner the column (32) on the condition of the heartwood. Referring to other columns, tree No. 42 is shown to have a total height of 53 feet (column 33), a full volume of 25 feet, board measure (column 35), a breast-high diameter of 5 inches (column 37), and is dominant (column 36); tree No. 27, on the other hand, has a total height of 60 feet, a full volume of 40 feet, board measure, a breast-high diameter of 6.65 inches, and is sufficiently overtopped and crowned by its neighbors to be marked intermediate.

The fact that the infected tree stood fairly in the open, with no deteriorating agents other than mistletoe associated with it, leaves small room for doubt that the tree was suppressed by the parasite upon it. Table II shows that tree No. 42 has seven branch brooms (column 8), with an average weight of 3 pounds per broom (column 11) on and above the average weight of the normal branch, which is 2 pounds (column 10).

The effects of the mistletoe on its host are further shown by the differences in the diameters of branches supporting brooms and those not so encumbered (columns 12 and 13). The analysis of these trees showed that both individuals started equally, but the measurements and study of all cross sections showed plainly a retarded growth during the last few years of life except at the stump, the section passing through burl tissues (column 40). The age of the tree can not be held responsible for the falling off in increment. A comparison of the measurements taken at the various cross sections and at

the stump was found to vary so little that the stump measurements were adopted to show the falling off in growth for the last 10 years. A study of all the cross sections of tree No. 27 showed a normal growth. It also possesses a crown of larger dimensions. The two trees stood within 100 feet of each other. Selecting from Table II that which is of greatest moment, trees Nos. 43 and 9 may be compared as shown in Table III.

TABLE III.—*Condition of larches Nos. 43 and 9, selected from Table II for comparison.*

Item of comparison.	Tree No. 43.	Tree No. 9.
Age.....years	96	96
Breast-high diameter.....inches	6	9
Infection	xxx	0
Average width of sapwood.....inches	1.12	1.35
Average number of rings in sapwood	23	27
Width of present zone of suppression.....{inches	0.4	0
{rings	30	0
Height.....feet	65	72
Merchantable length.....do	20	32
Full volume, board measure.....do	20	80
Growth for last 10 years.....inches	0.10	1
Relation to neighboring trees	Dominant.	Intermediate.

Tree No. 43, as shown by the data in Table II, had burls on its trunk and at the bases of branches (columns 3 and 15). A trunk burl occupied 100 per cent of its total circumference (column 20) and only 10 per cent of it was living (column 23). The tree had six branch brooms (column 6), with an average weight of 4.5 pounds (column 11), and normal branches of 3 pounds average weight (column 10).

In this manner tree No. 5 may be compared with tree No. 44; No. 10 with No. 11; No. 3 with No. 39; No. 5 with No. 25; No. 33 with No. 35; No. 2 with No. 12; No. 30 with No. 37; No. 33 with Nos. 35, 29, or 36; No. 18 with No. 34, etc.

EFFECT OF MISTLETOE BURLS ON THE MERCHANTABILITY OF LARCH TREES.

The effect of the formation of burls on the trunk and at the bases of branches, aside from injuring the tree from a physiological standpoint by cutting off the transporting tissues, introduces a cull factor of no mean proportion in the present timber capital. In bucking the tree it is possible in most cases to saw out the burls when they are far enough apart not to interfere seriously with the merchantable log length. In badly infected specimens the trunk and branch burls (figs. 5, 8, 9, and 10) are frequently so close together and so evenly distributed along the trunk that little merchantable material can be obtained. Sometimes these burls take up the entire merchantable

part of the tree and are very frequently more than 10 feet in length. Streaks of discolored wood, usually pitchy, and long checks may often extend from burl to burl, producing a very poor grade of lumber. Table IV shows the quantity of culls resulting from the mistletoe burls.

TABLE IV.—*Culled larch lumber resulting from mistletoe burls.*

Age of tree.	Tree No.	Trunk burls.						Basal branch burls.			
		Burl No.	Average diameter.		Length.	Volume, b. m., of culls due to burls.		Maximum diameter.[a]	Number.	Volume, b. m., of culls due to burls.	
			At base.	At top.		Each.	For tree.			Each.	For tree.
Years.			*Inches.*	*Inches.*	*Feet.*	*Feet.*	*Feet.*	*Inches.*		*Feet.*	*Feet.*
90	6	1	6.6	6.1				7.0			
		2	3.5	3			(b)	3.5		(b)	165.0
96	43	1								(b)	20
100	7	1	12.3	12	1.5	12	26.8	12.3	3	1.4	28.2
		2	11.5	11	1.2	9.3		11.5			
		3	10.1	10	1	5.5		10.1		1.4	
105	8	1	15.1	14.8	3	25	25	15.1	1	2.5	27.5
106	10	1	8.1	7	9	14.5	14.5	9	1	1.4	15.9
122	25	1	13.5	12.7	3	20	20	13.5	8	20	40
123	5	1	8.6	8.3	2	8	8	16	2	5	13
128	13								3	10	10
145	3c	1	12	11.8	2.3	15	37.5	12	5	30	67.5
		2	11.6	11.5	2	10		11.6			
		3	11.4	11.3	2	6.5		11.4			
		4	10.8	10.6	2	6		10.8		30	
180	23								12	180	180
183	31	1	23.2	23	3	70		23.2	6	175	245
205	15	1	13.1	13	3.5	25	(d)	15.5	12	170	195
216	16	1	18.5	18	4	67.5		18.5			67.5
222	17	1	18.1	17.9	16	190	212	20	5	80	292
		2	17.7	17.5	2	22		18		80	
224	36								5	30	30
225	29	1	13.1	13	2.5	20		13.5	4	20	40
226	35	1	12.8	12.3	4	25		12.8	12	140	165
227	33								9	190	190
229	28	1	18	17.8	7	110		18	11	150	260
233	34								5	60	60
235	18								6	80	80
245	30								5	70	70
245	37								4	60	60
248	32	1	10.9		16	70		12	7	75	145
249	2								21	190	190
249	12								10	110	110
252	38								6	95	95
253	20	1	13	17.8	16	210	(c)	19	3	120	330

[a] Average diameter taken between middle line of burl and either extremity.
[b] Tree culled.
[c] See figure 8.
[d] See figure 10.
[e] See figure 9.

METHOD OF CONTROL.

Since mistletoe is propagated and spreads from tree to tree by means of seeds, the method to be employed in eradicating it is similar to that which is now being adopted in many sales areas for reducing the ravages of forest-tree fungi. Results will be obtained in a much shorter time, however, than in the case of fungous enemies. Mistletoe occupies only the aerial part of the host. Fungi attack all parts—roots, stems, and leaves; hence, cutting an infected tree does not

eliminate some of the worst fungous enemies of the forest. Those of the roots escape and others attacking the aerial portion of the tree afterwards in many cases develop quite as vigorously on the dead wood as before. On the other hand, the mistletoe plant dies with the death of the host. Although the seeds of the mistletoe are expelled from the pericarp with considerable force, they are not carried, even though aided by wind, for great distances, as are the spores of fungi. Birds and rodents [1] are factors in the distribution of mistletoe seeds, but the actual service rendered the parasite by such agencies is very small. It is very evident, then, that no trees, young or old, infected with mistletoe should ever be selected for seed trees, because all young growth beneath such trees and in the near vicinity would be in great danger of infection. By a gradual process of elimination on every timber-sale area, governed by a clause in the contract requiring the taking down or girdling by fire of every mistletoe-infected tree, much may be accomplished within a comparatively short time.

CONCLUSIONS.

The principal conclusions which may be drawn from the present study are summarized as follows:

The deterioration of the western larch in the more open and exposed stands of the Whitman National Forest is due to mistletoe. Although yellow pine and Douglas fir are the most valuable species, the larch, when free from mistletoe, attains a size on any site, so far as observed, sufficient to merit its being carried along in the rotation with the other species. From the fact that the larch mistletoe finds its optimum development in the more exposed sites, future silvical operations should aim at confining the larch to moist bottoms and protected valleys.

Since the principal defects of the western larch, excluding pitchy butt and shake, originate from mistletoe, the diameter and age limit of this tree may be greatly extended, provided methods for the eradication of the mistletoe are adopted.

The larch mistletoe attacks trees of all ages, from seedlings to the unsuberized parts of mature trees. If not entirely suppressed or killed, trees attacked in early life seldom produce a good grade of merchantable timber. All trees seriously infected show poor health and reduced diameter or height. Trees becoming infected in middle life may have the quality of the timber reduced by the large knots formed by the basal branch burls.

[1] The common English sparrow has been observed by the writer to feed upon the seeds of the yellow-pine mistletoe in the city park at Coeur d'Alene, Idaho. Mistletoe seeds have been found in the excrement of birds in mistletoe regions. Birds and rodents frequently build their nests in mistletoe brooms and are known by actual investigation to play a minor rôle in the distribution of the seeds of the parasite.

Burls found in early life on the trunk cause suppression by reducing the food-transporting tissues, form open wounds for the entrance of fungi and insects, and cause streaks of pitch to appear in the wood, which often extend from one burl to another. Burls formed at the bases of branches produce similar injuries and may also cause a premature pruning of the branch.

The extra weight of the brooms, together with the accumulated débris, causes the branches to break off readily under the influence of the wind and deprives the tree of its normal food supply.

Mistletoe thrives best on trees of uneven stands. In dense, close, even-aged stands, as in deep valleys, the parasite usually causes less damage.

The type of infection working the greatest injury in the shortest time is the formation of brooms on the branches.

Thinning promotes the development of the parasite in the crown; hence, all infected trees of any size, age, and condition should be marked for cutting.

The mistletoe spreads more rapidly in the crowns of younger trees, owing to the greater number of twigs in close proximity susceptible to infection.

Two types of infection by the mistletoe occur: (1) By the seed falling on the branches, where a broom usually develops if infection occurs, and (2) the gradual advance of the cortical root system of the mistletoe along the branch to younger tissues. The seeds of mistletoe have been known to fall on the healing tissue of wounds on old parts of trees, causing infection.

Suppression by mistletoe causes a more rapid and an earlier formation of heartwood in the younger age classes, thus inviting insects and fungi at earlier periods of growth.

Mistletoe may be controlled by inserting in all timber-sale contracts a clause requiring the cutting on the sales area of all larches infected with mistletoe, whether merchantable or unmerchantable.

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